LIVING THINGS

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by

J. W. N. SULLIVAN

With pictures by

L. R. Brightwell

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NOTE

THE language used in this book is an international form of English named Basic English. A small number of words, such as *evolution* and *microscope*, which are current wherever there is a knowledge of science, are used freely in addition to the 850 Basic words. All other words have their senses made clear in the book.

Names of chemical substances have their international signs printed after them the first time they are used. In the same way, all names of animals and plants, other than those which have a place in the Basic Word List, are given with their international Latin names.

BOOK I.—THE SIMPLEST LIVING UNITS

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§ 1

THE WIDE RANGE OF LIVING THINGS

ALL the substances of which material things are made are formed from ninety-two separate 'elements'—that is, from ninety-two substances which are so simple that we are unable to get them broken up into anything simpler. Of these ninety-two elements, we have up till now come across only ninety, so there is clearly not very much of the other two in existence. And a great number of those of which we have knowledge are present only in very small amounts. It is possible that there may be elements in the stars which are not on the earth at all, but we have no experience of any such elements.

Tests of the light which comes to us from the stars give no sign of any new ones. Hydrogen (H) is the element of which there seems to be most in existence, because the stars are chiefly made of it. The element of which there is most on the face of the earth is oxygen (O). Substances other than those which are present in living bodies (I am talking here only of the top covering of the earth) have a greater amount of oxygen in them than of any other element. And even in the substances which are in living bodies oxygen is one of the chief elements present.

The number of chemical elements present in living bodies is quite small, but the substances formed from them are more complex than any substances which are not a part of living material. Chief among the elements forming the material of living bodies are carbon (C), hydrogen, oxygen, and nitrogen (N). In addition to these there are twelve or more other elements, but they are present in smaller amounts. In the living body the substances formed by these elements are very complex, and very delicate in their reactions to outside conditions. A degree of heat well under the boiling-point of water is generally enough for the destruction of living things, though some seeds

and 'spores,' which are little grains of living material with a hard covering round them, are able to go on living at a heat of 120° C. and more. Certain very low forms of plant, however, are able to go on living in very great degrees of cold. Bacteria and the spores of fungi have been kept for days at a time in the degree of cold at which air becomes liquid, and have gone on living. Certain animals in moss (*Musci*) have even gone on living in the degree of cold at which helium (He) becomes liquid. This is only four degrees over — 273° C.

Animals and plants are the two chief divisions of living things. The line between them is generally quite clear. But there are some things for which the normal tests are no use. We are unable to say, for example, that all animals have the power of moving about and that plants do not. Some animals, as sea-squirts (*Tunicata*), are rooted in one place, and some plants go from one place to another. Where plants and animals are truly different is in their food. Plants are able to get the elements necessary for existence straight from the air, earth, and water in which they are living. Animals have not the power to make use of these elements in their simple condition; they have to be given

them in highly complex forms. The process of building up the elements into these highly complex forms is done by the plants. If we go back far enough, we see that animals are completely dependent on green plants. Green plants, in their turn, are unable to make use of their food without the help of the sun's rays. The sun's heat is necessary to the chemical food processes of plants. In this way all forms of living material are, in the end, dependent on the heat of the sun.

One of the most surprising facts about living things is that they have such a number of different forms. The powers of invention which have gone into producing these forms are on quite a different scale from those of man. Take, for example, the range in size. One drop of water would be great enough to have in it about 300,000,000 of the body which is the cause of malaria. At the other end of the scale we have some of the whales (*Balaenidae*), which may be almost 100 feet long and have a weight of 150 tons. Some plants are even greater in size. One of the great trees of California may have a size ten times that of the greatest whale. We see that, in addition to being so different in size, living things are very different from one another in all other qualities—in colour,

form, ways of living, etc., etc. Naturally it is not at all a simple business to give an ordered grouping to such widely different animals.

It is, in fact, not possible to make a division into completely separate groups. Even the division into animals and plants is not complete, because there are things which have animal and plant qualities together. They have the power of building up their food from simple substances like a plant, and are at the same time able to take in complex substances like an animal. But the system of grouping worked out by biology experts for all the animals and plants of which we have knowledge is one covering almost all the field without question. Though there are such a number of different sorts of animals, the number of different designs on which their structure is based is quite small. For example, animals as different as a man and a frog (*Rana*) are made on the same general design, and come into the same great division of *Vertebrata*. The lobster (*Homarus vulgaris*), on the other hand, is put together in quite a different way, and is placed by the biology experts in another of the great chief divisions. Such animals as the snail (*Helix*) and cuttlefish (*Sepia*), again, are in another great division. There are about twelve such

divisions. Inside these chief divisions we make the discovery that certain smaller divisions are possible. Other divisions are made in these smaller groups, and so on. The last grouping of all in this process of division is into 'species.' Animals of the same species are so like one another that no further grouping is possible. For the purpose of anyone building up a system of biological divisions, animals of the same species all have the same qualities. We would only be able to take the grouping further by noting the small ways in which groups of animals of the same species were different, and, at last, by noting every separate animal.

But this idea of species is not completely clear-cut. It is sometimes not possible to say if an animal is of one species or of some other very like it. So far, no one has put forward a system of marking off the different species which may be used for all animals without any chance of error. This fact gives support to the idea we now have that species are not fixed things, separately formed, but all have some common starting-point. In fact, there are persons to-day who take the view that every form of living thing, animal and plant, has come by changes which have taken place over a great number

of millions of years, from some very simple first seed of living material. On this view, though a man is so very different from, say, starfish, we will make the discovery, if we go back far enough, that they and all other forms of living thing had a common starting-point. We will see later that there are a number of facts in support of this view, but we will make a start by saying something about a great and important fact—the 'cell' structure of living material.

§ 2

THE SIMPLEST LIVING FORM

It was not till about 1650 that microscopes were made which were good enough to be of any use. By using these, Malpighi and Grew made the discovery that plants are formed of a number of little structures to which they gave the name 'cells.' These cells are like very, very small boxes put tightly together. In the living plant these boxes have in them a soft, smooth, almost liquid substance named 'protoplasm.' Later it was seen that it is what is in the boxes, and not the boxes themselves, which is the important thing in the structure of plants. For this reason, when talking of the cell structure of plants, we now have in mind not the box-like framework but the protoplasm which is in the framework. With this changed sense the word 'cell' is, it is true, not a very happy one. History is responsible for its use. It is even less happy

when used in connection with the structure of animals, because here the 'cells' are without cell-walls, and may even be small moving bodies of different sizes and forms.

A cell is generally a flat, round body, so small that it may only be seen under a microscope. But there are a number of other sorts of cell. Cells may be like balls, or square bricks, or stars, or thin threads. And some may very readily be seen without a microscope. But it will be enough, for the present, to say something about the normal form. A cell is made of an almost liquid, almost completely clear substance of a chemical structure so complex that we are still unable to give a full account of it. The cell is generally covered by a cell-skin controlling the amount of material going into and coming out of the cell. Somewhere about the middle there is generally a round thing named the 'nucleus,' and this, like the cell itself, is covered by a special skin. The substance round the nucleus is named the 'cytoplasm.' This, when looked at with care, is seen to be of very complex structure, having in it small grains, thin threads, and drops of oil, all of which are in motion.

The cell may be taken as the lowest,

simplest living form. All higher forms are made of cells. But a cell, though so simple a thing in comparison with the higher forms, is able to have a separate existence. Cells taken from different parts of a body will go on living for an unlimited time if kept in the right conditions. In fact, there are certain living bodies, having an independent existence, which seem to be formed of nothing but one cell. Such bodies are named 'unicellular.' A noted example is the amœba, which one comes across in the green material formed in dirty water.

This animal may be seen only under the microscope, and seems to be simply a bit of protoplasm, but for the fact that it has a nucleus. In addition to the nucleus one sees another structure named the 'contractile vacuole,' which regularly gets greater in size from time to time, bursting, and then forming again. This is an apparatus for sending out the water which keeps getting into the amœba. Outside these structures the amœba has not any of the parts which are normally looked for in an animal. But the amœba has the power of moving about, of taking in food, of digestion, of breathing in oxygen and giving out carbon dioxide (CO_2), and of producing other amœba. It

gets about by sending out tongues of itself, and then, as one might say, running into these tongues. It gets its food by folding itself round the very small plants, etc., which are its food, and after the digestion of whatever is of use to it in this food, it then goes away from the waste material. It takes in its oxygen and gives out its carbon dioxide anywhere on the outer part of its body. But possibly the strangest thing about it is its way of producing other amœba. It does this by separating itself into two halves, which become two complete amœba. It is necessary for the nucleus to take part in this process so that its division between the two halves is equal. When these halves have become complete amœba, the same division takes place in the two animals, so that four animals are produced, which again go through the process of division, and so on. In this way the substance of an amœba never undergoes death. It goes on living in its offspring. Division takes place in some of these animals every hour. If we made a start with one amœba, letting the process of division go on without putting anything in its way, then in about a day the water they were in would be a solid mass of amœba. In a week the mass of amœba formed from one animal

would be very much greater than the mass of the earth.

Is it possible to say that the amœba is conscious? Certainly its acts are very like those which are talked of as conscious in ourselves and the higher animals. It has quite a clear reaction to changes in degrees of light, for example. It seems to have the power of controlling its motion. And it makes a selection of its food. It does not take into its body whatever comes its way. It gives no attention, for example, to hard grains of stone which would give trouble to the digestion. Our natural tendency is to say that behaviour of this sort is conscious behaviour. It is not impossible, however, to take the view that such behaviour is like that of a machine, in the sense that it is completely the outcome of the laws of physics and chemistry. It is possible to make something whose behaviour is more or less like the behaviour of an amœba. If drops of chloroform ($CHCl_3$) are put into the right sort of liquid they will be supported in the liquid, and on coming up against small grains of wax they will get all round them very much as an amœba gets round its food. Again, by using certain chemical reactions, it is possible for the process of cell-division by which the amœba

makes itself into more amœba to be, in some degree, copied. Nobody makes the suggestion, however, that doing these things makes the amœba's behaviour any clearer to us. All they do is to give us the idea that it is possible that the behaviour of the amœba is like that of a machine.

It is not very probable, however. The chemical substances of which a living cell is formed are so complex that chemists have still very little knowledge of what they are. And the distribution of these substances in the cell, what they do together, what their reactions are, how they keep the amœba as a complete and separate unit—all this, we are still in the dark about. There are a number of biologists who are of the opinion that it is not possible to give an account of how the amœba came into existence, its structure, and its behaviour as a living cell without going outside the laws of physics and chemistry. There are other biologists who have a fixed belief that such an account of living things will one day be given. So far as science has gone at present, however, we have not got anywhere near being able to give an account of living things which is based completely on the laws of physics and chemistry.

There are even smaller living units than cells. There are, for example, the bacteria, which are hundreds or even thousands of times smaller than the cells which we see through a microscope. These small bodies have no special parts. There is nothing like the nucleus of the normal cell, for example. They seem to be one substance all through. Their numbers are increased by the simple process of division into two, and this process has gone on at a great rate. Division takes place in a normal bacterium after about twenty minutes. We see that, if nothing got in the way, their rate of increase would be even greater than that of the amœba.

It is common knowledge that bacteria are the cause of a number of diseases, but at the same time there are a number of ways in which they are of use to us. They are important in farming, for example, because there are bacteria which make the nitrogen of the air into substances which plants are able to take in as food. Animals with feet of horn and other animals living on plants would be unable to get any food-value from grass but for the help of the bacteria living in the digestion pipe. In addition, bacteria, by causing things to go bad, make it possible for the chemical substances of dead bodies

to come into use again. There are a great number of species of bacteria, of different sizes and forms, and they are present in great amounts everywhere—in earth, air, and water. Generally death comes about straight away if they are heated to the boiling-point of water. But bacteria, to keep themselves from danger, are able to take the form of spores, and in this form their destruction is not such a simple business. They are able to go on living in heat equal to that of boiling water for hours, and in cold equal to that of liquid air for months.

Bacteria are the smallest animals we are able to see, even with the best microscopes, but there are good reasons for the belief that there are even smaller animals in existence. This discovery was first made in connection with foot-and-mouth disease. Here is a test one may make. One takes some of the liquid from one of the poison-pockets which are formed on the lips and feet of an animal which has this disease. Then one puts the liquid through some very small-grained substance, such as that of which delicate teacups are made. Such a substance will do the work of a 'filter,' letting the molecules of the liquid through, but not letting through any of the bacteria one sees under the micro-

scope. But, though no bacteria get through, the liquid which has gone through the filter will give foot-and-mouth disease to another animal. Further, the liquid taken from this second animal may be used to give the disease to a third animal, and so on. The disease does not get feebler in the process of being handed on from one animal to another. It is clearly caused by something which, though we are unable to see it, has the same power of increasing its numbers by division as a bacterium. These bodies are named 'filter-passing organisms.' We have knowledge of quite a number of species of them, every one producing its special sort of disease. There is a belief that the common cold may be produced by these bodies.

There are signs of something even smaller, named a bacteriophage, living on and causing the destruction of bacteria. We say it is a 'something,' because it has been seriously questioned if it is a living body at all. It clearly has some of the properties of a living body, but it is sometimes looked on as a sort of half-way house between living and not-living substances. It has been worked out that the bacteriophage is so small that it does not have in it more than about 1,000 molecules.

In all bodies other than these, which are so small that we are able to see them only under the microscope, or even not at all, the normal form of living material is the cell-form. All higher structures are made of cells. Skin, bone, nerve, muscle, etc., etc., are all made of cells. And these cells, different in form, size, and behaviour, all do their work together in the interests of a greater unit—the body. But a complex living body, such as the body of a man, is not formed completely of living cells. The cells of bone and certain bone-like material, for example, give out dead substances from themselves, so building up the framework. An account of the different cells of the body and of the way in which they do their work together would become a complete account of physiology, but we may here say something about a very important group of cells—the blood cells.

Blood is chiefly water which has in it a great number of chemical substances. But about one-third of all the blood in our bodies is formed of cells—the red and the white cells. Of these, the number of red cells is far the greater, there being about six hundred red cells to every white cell. It is the red cells which give our blood its colour. This

is caused by a colouring substance in the red cells which is named 'hæmoglobin.' These red cells seem to be of the same structure throughout. They have no nucleus. They are round and flat in form, and they are thinner in the middle than at the edge. They are great enough to be seen by the normal sort of microscope, and they are present in very great numbers. The body of a man has in it about 20,000,000 of them. Their chief use is to take the necessary amounts of oxygen through the body. The white cells are somewhat greater in size, they have nuclei, and some of them have the power of moving independently. There are about six different sorts of them, every one of which has its special uses. All these uses have to do with fighting things which are a danger to the body. The small animals and disease bacteria which get into the body are attacked by the white cells.

Men, and, in fact, all higher living beings, are formed, as we have said, out of cells of different sorts, in relation to the purposes (of the muscles, nerves, and so on) for which they are needed. The growth in size of any part of the body is caused by an increase in the number of cells of which it is made. In this way a man is truly a great society of cells,

every sort of cell doing its special work, and at the same time controlled by surprisingly delicate organization and working with all the other cells in the interests of the complete body

§ 3

THE DEVELOPMENT OF A LIVING THING

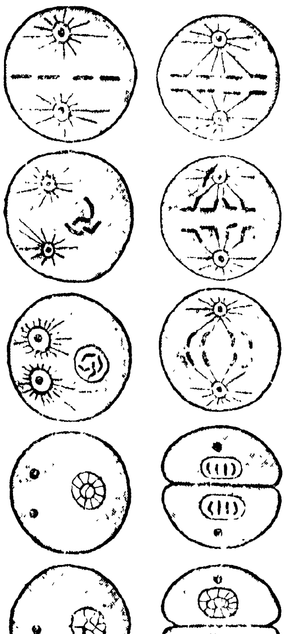
ALMOST all living things come, in the first place, from one cell. A division takes place in this cell, and two cells are produced. In every one of these cells division again takes place, and so on. This process of cell-division, when looked at in detail, is seen to be very surprising. It takes place in three stages. In the first stage the liquid substance in the nucleus becomes changed into a number of little rod-like bodies, and the wall of the nucleus gets broken down. These little rod-like bodies are named 'chromosomes.' In every chromosome a division takes place from end to end into two halves, and the two halves become separate, as if they were being pulled away from one another by the threads which are fixed to them like rays. A division of the cell itself now takes place in the space between the two

groups of chromosomes. In this way the two half-cells have a complete number of half-chromosomes. (See picture on page 39.) The half-chromosomes then come together again, forming two new nuclei, and in the end we have two cells which are the same in every detail as the mother-cell.

It is by this long process of division that the development of most living things comes about. But the cells of which one animal is formed will naturally not be the same as the cells of which some completely different animal is formed.

It is said that when cells are different it is because their chromosomes are different. Chromosomes are, in fact, different in size and form. And the cells of different animals frequently have different numbers of chromosomes. The cells forming the body of a man, for example, all have forty-eight chromosomes. With some animals every cell may have a hundred or more chromosomes, with others there are only two or three in a cell. But the cells of the same species of animals or plants all have the same number of chromosomes.

The cell which is the starting-point for the development of a living thing generally comes, in the first place, from the uniting of



The process of cell division. See account.

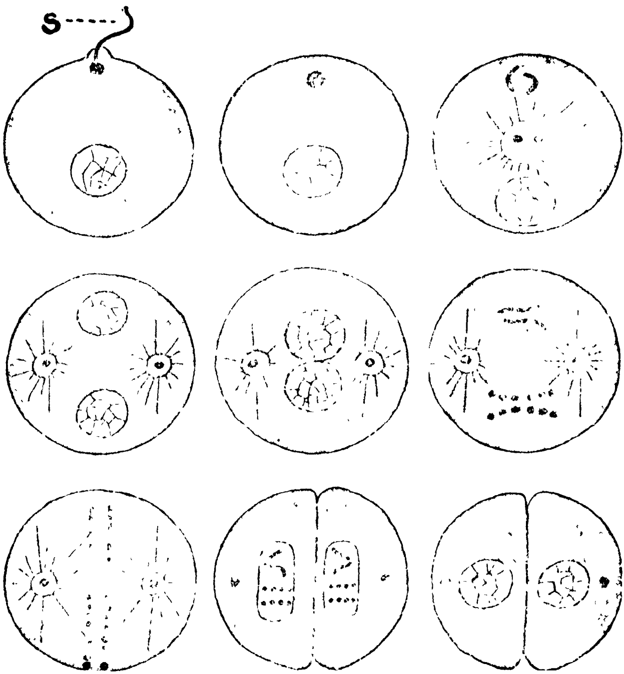
two cells, one produced by the male and the other by the female. That is true of most plants, and of the higher animals. The cells which do this work are different from all the other cells in the body. They have only half the number of chromosomes, for example. Because these cells are unlike the others they are given a special name. They are named gametes, while the other cells are named zygotes. The process of forming gametes is naturally different from that of zygotes. Two gametes are formed from a cell which has the full number of chromosomes natural for that animal, whatever it may be ; but in the process of division, the chromosomes do not come in half. There is no change in them at all, but half of them go to one daughter cell and half to the other. So, in the body of a man or woman, a cell with forty-eight chromosomes in it will, if gametes are to be formed from it, undergo division into two cells of twenty-four chromosomes.

When the male and female gametes, named spermatozoon and ovum, are united, they become one, producing a cell which has the normal number of chromosomes, and this cell, by division in the normal way, in time makes all the cells needed for building up the body of a new animal. This is the system of

producing new living bodies by the sex process, and it is the process common to most living things. A gamete from the male becomes united with a gamete from the female and a new thing is produced.

We have seen that the numbers of very simple, one-celled animals, such as amœba, are increased by normal cell division. That is to say, the chromosomes come into two halves, so that every daughter cell has the same number of chromosomes as the mother cell. In bacteria, as we have seen, the numbers are increased by simple division into two. With such simple structures there is no such thing as male and female. The division into male and female, and the system of producing new beings by the sex process, is clearly something whose development did not take place till after the simplest stage was over. These special cells, the gametes, are stored in special parts of the bodies of all males and females, and it is only when a gamete from the female becomes united with a gamete from the male that a new being comes into existence.

It was the belief at one time that some small living things come into existence from nothing. The observation was made that there are masses of little animals to be seen



The process of cell division. See account.

in such things as meat when it is going bad. The belief was that these animals are somehow produced by the process which makes meat go bad. But we have made the discovery that when the necessary care is taken to keep the meat clear from spores, etc., in the air, no development of living things takes place. It is now certain that in every example which has been under observation, living things come from other living things. This fact makes it very hard for us to have any idea of how living things first came into existence on the earth, because it seems to say that living things have been in existence from the very start. At the same time, however, we have no doubt that early conditions on the earth, its heat, etc., made the existence of any living thing impossible. For this reason, most biology experts take the view that living things did, in the first place, come into being from nothing. They have the belief that certain chemicals came together, forming complex substances which then took on the properties of living things. But there is no way of testing such a theory, so at present it is simply a question of belief. The other possible view for us to take is that living things came to our planet in the form of bacteria journeying through space. It is

possible that these bacteria came in the first place from some other planet on which living things have come into existence. But by saying this we are only pushing the question mark one stage further back. We still have to give an account of how living things came into existence on the other planet. For the theory to be of any help, we have to say that these bacteria have been present all the time —that living things are as old as substance itself. It does not seem at all probable that, in the conditions of outer space, living bacteria would be able to go on moving about for an unlimited time. So one is more or less forced into the view that living things came from material which was not living, though the theory seems an improbable one in a number of ways, and our observation has given us no facts in support of it.

§ 4

THE HANDING DOWN OF QUALITIES

WE have said that the qualities an animal has are dependent in some way on the chromosomes in the cells of which it is made. Tests have made it clear that the units which give an animal its special qualities are inside the chromosomes of its cells. These units are named 'genes,' and there are a number of them in every chromosome. Genes are so small that we have no way of seeing them, and so there is no way of making certain of their existence by simple observation. Their existence, like that of atoms, is pointed to by a number of tests. Sometimes one gene is responsible for one quality, but this is far from being true of all genes. It would not be true to say that all genes are completely independent of one another, one gene being responsible for eye-colour, another for form of wings, etc., etc. Things are not all as

simple as that. Sometimes a quality is produced by two or three genes acting together. But, working separately or in groups, the genes are the units which make possible the handing down of qualities from one animal or plant to another.

The first person to make the discovery of the laws by which qualities are handed down in this way was an Austrian man of religion named Mendel. For some years no attention was given to his work. Then the records of the tests he had made came to light, and from that time much work has been done on the question. It will be best if we give our account of the facts which Mendel put before us in relation to the much later discovery of chromosomes.

The normal zygote cell has cells of such a number that division is possible by two. When the zygote is about to be changed into two gametes, the chromosomes get into groups of two, and in the process of division, one half of them goes to one gamete and one half to the other. These two gametes, formed from the same zygote, may in this way have different sorts of chromosomes. Take, for example, a light red flower which is formed by uniting a red and a white. The colour of this flower is the outcome of two

colour units, one red and one white, which it has got from the father and mother plants. Every one of its zygotes, having the full number of chromosomes, has a red and a white unit. But when the division of the zygote takes place and two gametes are formed, we make the discovery that the separating of its chromosomes is done in such a way that the white unit goes to one gamete and the red to the other. Now these gametes are waiting to be made fertile, that is, every gamete is waiting to be united with a gamete from another plant. Let us say that these other gametes come from another light red flower. Then one of these gametes will have a white unit and the other a red unit. It is quite simple to see what the possible groupings are here. We may have two white-unit gametes uniting, or two red-unit gametes uniting, or we may have the white of the one uniting with the red of the other. This last grouping is truly two groupings, because we may have the red of the first flower uniting with the white of the second, or we may have the white of the first flower uniting with the red of the second. The two groupings have the same outcome naturally—a light red flower. From the other two groupings is produced, on the one hand, a red flower, and

on the other, a white flower. In this way we see that a light red flower is not produced through a white and a red flower being mixed. In the cells of which it is formed, the zygotes, it has the two units, the red and the white They do not become mixed, but have a separate existence side by side.

The zygotes of a light red flower, as we have seen, have one red unit and one white unit. In a red flower there are two red units, and in a white flower two white units. For this reason, the two gametes formed by a zygote of a red flower will necessarily have red-producing units in them. And in the same way the gametes of a white flower will have white-producing units. With this knowledge, we are able to say what groupings are possible when, say, a red flower is made fertile by a light red flower. We see that the outcome will be light red or red. If the qualities of two plants were simply mixed in the new plant, this outcome would not be looked for. The natural outcome of uniting a light red and a red would be a darker shade of light red.

So far we have been talking simply of the units producing colour. But the same general rule is true whatever unit we take. That is to say, the qualities handed down are not the

mixed qualities of the male and female cells producing the new plant. And all the different units, responsible for all the different qualities of the living structure, do their work independently of one another. For example, a plant, in addition to having colour units, may have size units. In addition to red and white units, it may have short and tall units. The discovery has been made that these two groups of units do their work quite independently of one another. Its colour has no effect on how tall it is. It is possible for tall and for short plants to be red or white. If we take a great number of units into account, as we have to do, naturally, with any one structure, then the number of different ways in which qualities might be grouped together is very great. But it would not be true to say that all these groupings take place. Sometimes the behaviour of two or more genes is such that they seem to be joined together. In some species certain qualities seem necessarily to go together. But, putting such examples on one side, it is true in the wide sense that the different qualities of an animal or of a plant are handed down independently of one another.

We are not able to go so far as to say that *every* quality which is handed down comes

from the genes. It seems from certain observations that the cytoplasm of the cell has something to do with it—at least sometimes. But the part it takes seems to be far less important. For most of the qualities of any living thing the genes are responsible. This is probably no less true of qualities of the mind than it is of physical qualities. In examples where there is a clear line separating a quality of the mind from the physical qualities, as in a man's powers of music, records make it clear that their behaviour is in harmony with Mendel's laws.

So far we have been talking of the laws by which qualities are handed down as if every quality had equal weight. We have been talking as if every gene had the power of producing its full effect. For example, we have said that the outcome of uniting a white flower with a red flower is a light red flower. The part played by the white unit and the red unit, we have said, is equal. Now this is far from being completely true. Frequently one unit is overpowered by the other. It is quite possible, for example, for a brown-eyed person to have one brown unit and one blue unit. The blue unit is overpowered by the brown unit. It is only possible for a person to be blue-eyed if the two units are

blue. It is not possible for a brown-eyed baby to be produced by a blue-eyed father and mother, because there is no brown unit for the baby to take. But it is quite possible for a brown-eyed father and mother to have a blue-eyed baby. Because the father may have, not two brown units, but a brown and a blue unit. And the mother may have the same. In this way it is possible for the baby to get two blue units, one from its father and another from its mother, and so be blue-eyed. A unit which has the effect of overpowering another unit in this way is named a ' dominant ' unit. The other unit is named ' recessive.'

Mendel's first tests were made with two sorts of peas (*Pisum sativum*), tall and short. The effect of making one of these sorts of peas fertile from the other was that the new plants produced were all tall. But the outcome of letting these tall peas make one another fertile was that some tall and some short peas were produced. The theory of dominant and recessive units makes the reason for this clear.

All the tall peas which were produced by the first process had a tall unit and a short unit, but the short was overpowered by the tall. Some of the offspring of these plants

would take the short unit from the male and female cells from which they were formed, and so would be short. Of the other offspring, some would be true talls, having two tall units, and the rest would be mixed talls, having one tall and one short unit.

In talking of dominant and recessive units, it is necessary to say that the line between them is not at all times completely fixed. The recessive unit is sometimes not completely overpowered by the dominant unit. It may come out in a more or less feeble and incomplete form. For example, it is possible for a recessive colour not to be completely overpowered by the dominant colour, but to come out as markings of some sort on the other. There are degrees of dominant and recessive.

We have seen that the genes, bodies inside the chromosomes which are so small that we are unable to see them through the microscope and have no certain knowledge of their existence, are the units by which qualities are handed down. If there is a change in the genes new qualities will be handed down. Such changes do take place by themselves. They are named 'mutations.' A mutation may be recessive or dominant. If it is recessive it may be some time before there is

any sign of it, because it is only by the uniting of two animals which have the same mutation that there is a chance of the new quality coming out in the offspring. Till then it will be present without giving any sign of itself. 'Albinism,' for example, a condition in which there is no colouring material in the hair and eyes, seems to be caused by a mutation which is recessive. A father and mother who give no sign of being 'albinos,' may have a completely albino baby. Mutations which are dominant naturally come out from the start.

If a mutation, specially a dominant mutation, gives the animal a better chance than those with which it is in competition, or in any other way makes it simpler for it to get a living, there will be a tendency for it to take root. In time there will be a tendency for the animals which have this mutation to take the place of those who do not. In this way the species will become changed. So, if mutations are frequent enough, we see that, in time, very great changes might be produced in this way. Mutations are, in fact, the material for the working out of the great changes which take place in the adjustments of animals and plants to their conditions. Mutations are taking place all

the time among living things, and the 'Theory of Evolution,' as it is named, makes the suggestion that these mutations are responsible for all the different sorts of living things which are on, or have been on, the earth.

The discovery has now been made that mutations may be produced by biologists. A number of fruit flies (*Drosophila melanogaster*) have had X-rays sent into them, and the outcome of this is that some hundreds of mutations have been produced. No change is seen in the fruit fly which has had the X-rays, but it then has offspring in which the new qualities are seen. It seems that the rays have an effect on the gamete cells in the body of the fruit fly. The offspring of these X-rayed flies are different from the normal in such things as eye-colour, size of wings, etc. The changes so produced become fixed. The new qualities of these changed flies are handed down to their offspring in a way which is in agreement with the normal Mendelian laws. Some of the mutations so produced are dominant, and some are recessive. Some of them are mutations which have been seen to take place in fruit flies under natural conditions, and some of them are completely new.

Sometimes mutations may be caused chemically. By giving certain caterpillars (early forms of *Lepidoptera*) food with lead and manganese (Mn) in it, a new sort of moth (*Lepidoptera heterocera*) has been produced. In place of turning into light-coloured moths, as they normally would, these caterpillars become dark-coloured moths. This change becomes fixed as the others do, and is handed down in agreement with the Mendelian laws, even without the help of special food.

It is very important to keep a clear line between these changes and changes which may not be handed down. It is sometimes possible, by changing the living conditions, for very marked changes in the plant or animal to be produced. There is, for example, a red sort of Chinese primrose (*Primula sinensis*) and a white sort. If the red sort is kept in a glasshouse at a very great heat, it is possible to get a white in place of a red flower. But if it is placed in normal conditions again, it will again have a red flower. The change produced in this way is not a fixed change which will be handed down.

In addition to the degree of heat, other outside conditions, such as the amount of

water present in the air, and light, may be used for producing marked changes in certain structures. Insects, specially, may be made to undergo great changes if given the right conditions. Most biologists, however, are in agreement, that so far there has been no clear example pointing to the fact that such changes may be handed down to offspring. It seems that such changes are limited to the body cells of the structure, and are without effect on the gametes. And it is only when there is some effect on the gametes that a change is handed down. In other words, qualities formed in a structure by its living conditions are not handed down. For example, any qualities of body or mind, good or bad, which we may get by development are not handed down to our sons or daughters. Physical training may make our muscle-power greater, but it will not make us give birth to babies with stronger muscles. Our industry in learning languages will not make our sons and daughters good at languages.

We see that it is very important to make a division between qualities which have been handed down and qualities for which the conditions of existence are responsible. Lamarck, the great French zoologist, put forward the theory, about a hundred years

back, that a living body may, by acts over which it has control, make changes in itself which it has the power of handing down to offspring. For example, he had the idea that the development of longer and longer necks in giraffes (*Giraffa camelopardalis*) came about through giraffes stretching their necks up to the higher branches when there were not enough leaves lower down. The neck of every giraffe got a little longer and this change was handed down to the offspring. There are still biologists who are more or less in agreement with Lamarck's general outlook, but most of them are against it. We may take it as very probable, though still not completely certain, that qualities whose development takes place in a body while it is living are not handed down.

If all living things have come from simpler forms, we will have to take it that this has come about through changes in the genes. We have still not made the discovery of the causes of these changes. As we have seen, they may in some degree be produced by men of science through the use of X-rays. Further, we have the knowledge that short waves are coming to the earth all the time from outer space. It may be that natural mutations are caused by these rays. But

that, at present, is a theory which is not based on any observation. It is our belief that mutations are the material on which evolution gets to work, and that mutations come about through changes in the genes, but we are unable at present to say anything certain about the causes of these changes.

BOOK II.—EVOLUTION

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§ I

SORTS OF LIVING THINGS

WE have seen that almost all living things, animals and plants (putting on one side for the present such low structures as bacteria, etc.), have the great common quality that they are made of cells. Further, most living things have the power of producing other living things by the sex process. Not quite all living things have this power. We have seen that in one-celled animals new animals are produced simply by division. And it is possible that, before division, two cells become joined together, and that these two cells are of the same sort. There is here nothing parallel to male and female. Such processes, however, take place only with very low forms. Of almost all living things it is true to say that they are made of cells, and that they have the power of producing other living things by the sex process.

Outside these two common qualities, the chief point to be noted about living things seems to be the surprising number of ways in which they are different one from another. But we have said earlier that, for purposes of biology, animals have been grouped in about twelve chief divisions, and that further groupings have been made inside these great divisions. The great chief divisions are named 'phyla,' and all the animals in any one 'phylum' have a common general design. The most important of these phyla, the one which has in it all the animals of the highest organization, is that named *Vertebrata*.

Most important of the great group of *Vertebrata*, are fishes, amphibians (*Amphibia*), reptiles (*Reptilia*), birds, and mammals (*Mammalia*). There is here clearly a very wide range, but the structure of all these animals is of the same general design. A fish and a man, for example, have much in common. They have head-bones and a backbone, a brain and a backbone cord, a heart, stomach, *kidneys*,* *liver*,† *spleen*,‡ etc.

* Two bodies forming liquid to take waste nitrogen material from the system.

† Part of system forming dark yellow, bitter liquid which gives help in digestion.

‡ Part of system, at left side of stomach in mammals, having effect on condition of the blood.

And the swimming parts of a fish are structures like tne legs and arms of men or other mammals. In an amphibian, such as the frog, we see things which are even nearer to the structure of a fish on the one hand, and even nearer to the structure of a mammal on the other. In fact, in the earlier part of its existence the frog is a very fish-like animal. The young frog, in the earliest stage, has no legs, and its breathing-structure is like that of a fish. Later, the development takes place in it of a breathing-structure like that of a mammal, and it gets legs and arms, complete with hands and feet. Amphibians are, as one might say, a half-way house between water animals and land animals. When we come to make a detailed comparison of birds and mammals, we will see that they, like these other groups, have much in common. And birds and mammals are the only animals which are warm-blooded.

A full account of the ways in which the different animals named *Vertebrata* are like one another would make a long book. The structure of all of them is the same in general design, though taking different forms, so that some animals have the power of living in water, others on the land, and others in the air. This fact gives one the idea that pos-

sibly all the *Vertebrata* may have come from one sor⁺ of animal. It is possible to have the picture of some early form of the group *Vertebrata* which was the starting-point for all these different sorts of animals.

Every one of the other great phyla has a different general design. Let us take, for example, the *Arthropoda* phylum. This has in it a great number of very different animals, such as lobsters, crabs (*Brachyura*), shrimps (*Crangon idae*), spiders (*Arachnida*), scorpions (*Scorpionida*), butterflies and moths (*Lepidoptera*), beetles (*Coleoptera*), ants, earwigs (*Forficulidæ*), centipedes (*Chilopoda*), etc. The general design of all these animals is quite different from that of the *Vertebrata*. Their hard framework is outside the body and has divisions running across it. Fixed to these divisions are different parts of the body, all of which have joins in a number of places like a folding rule. They have different purposes. Some are sense-structures, some are used for walking or swimming, and some are for taking in food. In addition to being different from the *Vertebrata* in these ways, the *Arthropoda* are blue-blooded animals, and their nerve-system is placed quite differently, running down the lower side. And then, all the parts inside the body are quite different. The

lobster, for example, has teeth in its stomach, it has no spleen, and its liver, in structure and operation, is very different from ours. Its kidneys are in its head, and its heart in the middle of its back. While in process of growth it has to give up its normal existence, because it first has to put off the outer framework in which it is prisoned, and then time is needed for the development of a new one of greater size. Certain of the *Arthropoda*, such as the insects, have a system of breathing quite different from that of the *Vertebrata*. They have a network of air-pipes going all through the body, having openings at a number of places in the body wall. Air is pumped in and out of these pipes by regular motions of the animal's body.

Enough has been said to make it clear that the *Vertebrata* and *Arthropoda* are different in very important ways. There are a very great number of different sorts of animal in these two phyla. The insects, which are only one division of the *Arthropoda*, have more species than all the other animals put together. But these phyla are very far from taking in all the different sorts of animal. The *Mollusca* are an example of another phylum based on quite another design. In it are such animals as the oyster (*Ostreidæ*), the snail, the octopus,

and cuttlefish. These animals have no hard framework at all, but most of them have hard outer coverings, sometimes in two parts, as in the oyster, and sometimes all in one, as in the snail. The greatest animals which are not among the *Vertebrata* are in this phylum, cuttlefish having been seen which are fifty feet long. There is another quite different design for the *Echinodermata*, covering starfishes, sea-urchins (*Echinoidea*), and so on. And other forms of organization are seen in the different sorts of worms, certain sea animals such as jelly-fish, corals (*Hydrocoralluiæ* and *Actinozoa*), etc., and the sponges.

The fact that every one of the great phyla has a general design makes it seem as if all the different animals forming a phylum may come from the same sort of animal. It is possible that one change after another in the common design would, in time, give us all the different animals which there now are. But naturally this is no more than an idea till we have facts which make it clear that such changes have taken place. The common points in their structure, however, do give some support to the view that all the *Vertebrata*, for example, have a common starting-point. We may say as much of all the other phyla, so that it might seem that all animal

existence comes from about twelve simple early forms. The second step would be to see if there was any way of cutting down this number, by working out connections between the great phyla, giving an idea of how they might all be branches of some one simple form. Biologists have been looking for points of connection between the great phyla, and their work has not been completely without fruit. But at present we are very far from being in a position to see connections between all the different phyla. For example, no one has so far been able to put forward any good way of bridging the division between the *Vertebrata* and all the other phyla.

Anyhow, this idea is all based on the theory that living things are able, by one mutation after another, to be changed into quite different animals. There is very good reason for such a theory, and it is based on a wide range of facts. Let us take first the facts in connection with the existence of 'vestiges,' or signs of structures which had a use at some time in the animal's history but are no longer complete. There seems to be no way of accounting for the existence of such vestiges, which we see in a number of animals and plants, other than by the theory of evolution. The

whale, for example, is a mammal, a warm-blooded animal breathing air, and seems to have come from some four-legged animal which took to the sea. The front legs have been turned into the front swimming-parts. In fact, inside these parts is the bone-structure of quite a good front leg. But there is no outside structure in the whale to take the place of the back legs. When the animal is cut open, however, one sees a small group of bones which is like the incomplete structure of a back leg. There seems no way of accounting for these if they are not vestiges of parts which were at one time of some use. There are the same sort of vestiges of back legs in snakes, and this, taken together with other points of structure, makes it seem probable that they come from some animal like a lizard (*Lacerta*). There are good reasons, as we will see later, for the view that the horse comes from a three-toed animal, and in the present horse, to the left and right of the toe which has become the hard 'hoof,' may be seen the vestiges of the other toes. Man himself has quite a number of vestiges —some authorities say there are more than a hundred. We have, for example, the muscles necessary for moving our ears, but almost all of us no longer have the power of

using them. At the lower end of the backbone we have the vestiges of a tail. In some animals the tail is quite a good size and it is of great use to them. In man it has become small and it has no use at all. There are a great number of other such vestiges, and examples might be given not only from animals but equally from plants.

These facts certainly make it seem very probable that, over a long time, very great changes in living things have taken place. This idea seems even more probable if we have some knowledge of embryology. We have seen that most living things come into being from the uniting of two cells, an ovum and a spermatozoon. The development of the animal from its starting-point till birth, that is to say, while it is an 'embryo,' is the field of embryology. This science gives strong support to the theory of evolution. Because, in the process of its development, the embryo of a higher animal goes through stages which are parallel to the lower living forms. The embryo of a cat, for example, or of a snake, a fowl, or even a man, makes a start as if it was going to become a fish. The structure of its heart, chief out-going blood-vessels, and breathing-system are like

those of a fish. The embryos of all the air-breathing *Vertebrata* go through these stages. The only possible reason which comes to one's mind is that these animals have come from a fish-like form. The changes may be worked out in more detail, and some authorities have gone so far as to say that the development of the embryo gives a sort of outline of all the stages of evolution which make the history of that special animal. This statement is now seen not to be completely true, because certain stages of evolution may be made much shorter in the development of the embryo, or even not take place at all. And further, stages in the development of the embryo are sometimes parallel not to the stage of full growth of some earlier animal but to its condition as an embryo. But the general lines of evolution seem to come out surprisingly clearly in the development of the embryo, and the only way of accounting for this development seems to be by a theory of evolution.

We have seen that detailed observation of the living things now in existence gives us strong support for the idea that there has been a process of evolution. The fact that the form of every sort of animal and plant seems to be based on one or other of a small

number of different general designs of structure, the fact that it is so common for animals to have vestiges which are of no use to them at all, and, possibly most important of all, the surprising process of development in the embryo, all give us the idea that a great number of the species in existence to-day have come from earlier, and frequently simpler and less complete forms. If we had the power of journeying back in time, then, if the theory of evolution is true, we would see certain great changes taking place in living things. Certain forms with a high organization would go out of existence completely. The place of others would be taken by a smaller number of simpler forms. If we went far enough back, we would, if we are to take the facts of embryology as our guide, make the discovery that there were no air-breathing *Vertebrata*, and that the animals of highest development among the *Vertebrata* were fishes. And so we would go on, till in the end we got to the very earliest form of living thing, whatever that may have been.

We are unable to make this journey in time ; we have no way of watching the process of evolution. But, by chance, the history of a great part of this process is recorded for

us in earth and stone. With these records before us, as we will see, it is no longer possible for the process of evolution to be looked on as an unsupported theory ; it has to be taken as a fact.

§ 2

THE HISTORY OF LIVING THINGS

We have a knowledge of what the earth is made of for quite a distance down. A number of cuts and cracks are frequently caused by natural processes. The railway cuttings and mines, etc., made by man, have given us other chances of seeing what the outer part of the earth is like. By looking at these we have made the discovery that the part of the earth which we are able to see is formed of beds of different materials, one on top of another. We have beds of chalk, sandstone, etc. By making detailed comparisons in all parts of the earth, geologists have got the right order of these beds worked out. That is to say, they have a knowledge of the order in time in which these different beds were put down.

From the time the earth became solid there have been frequent changes in the parts taken up by the sea and by the land, and in

the level of the land. Great mountain ranges have been formed, and then, over millions of years, their destruction has come about through the force of wind and rain. By going back into the sea, this high land has made the level of the water higher, so that from time to time more or less of the land stretches have been covered by sea. The different beds have been formed by the sea putting down first one material and then another. These beds were later forced up out of the water by the cracking caused in the outer cover of the earth when it got smaller, or by the bursting through of gases from the lower levels. With these changes in the earth's form there went, as observations by geologists make clear, great changes in weather conditions.

These processes are still going on. In 1912 the United States Geological Survey said that the level of land in the United States was going down at the rate of one inch in 760 years. That is to say, the rivers of that country are taking into the sea 783,000,000 tons of material every year.

Together with the earth itself, we see that any dead bits of animals or plants which are present will be washed away at the same time. When, after they have been in the sea

for a long time, the great beds of material which have been washed away from the land come up out of the water again, these bits of animals and plants will be mixed up in them. In this way we are able to say, by looking at such beds as may be got at for observation, what animals and plants there were on the earth in those far-off times. The outcome of our observation is very interesting and gives great support to the theory of evolution. Because we make the discovery, in harmony with that theory, that the simpler forms are in the earlier beds, and the more complex forms in the later beds. Further, we sometimes come across forms which are half-way between the earlier and later forms in the middle beds. There are enough examples of this sort, as we will see, to make the fact of evolution quite certain.

If all the beds, or 'strata' as they are named, of which we have knowledge were put together, they would be about a hundred miles thick. Naturally, these strata have not all been seen together at any one place. The chance way in which they are formed, dependent on special conditions, would clearly make that impossible. The different strata are at their thickest in certain places. But if all the thickest strata of which we have

record were put together they would be about a hundred miles thick.

So that these strata may be talked about more readily, a division of them has been made, for purposes of geology, into times, or 'eras,' which are like the divisions of a book. The earliest era, when the first strata were put down, is the Archeozoic era. Then comes the Proterozoic, and after that the Paleozoic, in which species of *Vertebrata* first come into existence. After that there are two more eras, the Mesozoic and the Cenozoic; the last of which comes up to, and takes in, the present day. It has been worked out that the earth is roughly 2,000,000,000 years old. The numbers of years given by geologists to the different eras give support to this. It is not possible to get any clear idea of how long the Archeozoic era was, but it has been worked out that we are about 1,000,000,000 years away from the start of the Proterozoic era, 500,000,000 from the start of the Paleozoic, 175,000,000 from the start of the Mesozoic, and about 50,000,000 years from the start of the Cenozoic, or present era.

For an account of the earliest forms of living things which came into being on the earth, we are dependent on our powers of

building up a picture, guided naturally by a sense of what is possible based on a knowledge of science. There are no records in stone of the earliest forms of living things. No doubt they were so small and soft that no such record was possible. Probably they were little things like bacteria, because it is hard to see how anything so complex as a cell would have been able to come into existence out of nothing.

There are signs that the development of living things had gone a long way before they made any record on stone. The reason probably is that the early animals had no structure which was hard enough. The hard parts of an animal are formed through using calcium (Ca), and the calcium-using process was quite a late development. Throughout the Archeozoic strata there are almost no signs at all of living things. There are signs of the possible existence of some simple plant forms and worm-like animals. Let it be noted that, even in such records, quite a high degree of development is pointed to, because there were certainly other living forms between the plant and the worm. And these forms themselves are a long way from the one-celled structures which no doubt came before them. As we

are able to say from our observation of present living forms, there are a number of steps between a one-celled structure and such an animal as a worm. If we are right in our belief that there were worms in the Archeozoic, that fact is a pointer to the existence of a wide range of other living forms. The records of living things in the Proterozoic era are not at all full, but we have clear signs that, by the end of that era, most, if not all, of the phyla up to the *Vertebrata* had come into existence.

By the time we come to the third, or Paleozoic, era, the calcium-using process is quite common, and we have very full records of quite a number of animal forms. In this great era a very wide range of animals came into being, some to be changed into other forms which are now common, some to go completely out of existence, some to go on, almost unchanged, up to the present day. The development of all the phyla but the *Vertebrata* in the Paleozoic era is chiefly one of detail. But a very important event, possibly the most important event in the history of evolution, took place in this era. That was the development of the *Vertebrata*.

The bad point about the structure of animals without a backbone is that it makes

it hard for them to become strong and quick-moving. It is at its best when conditions are such that it is not necessary to put up much of a fight for existence. A sponge, for example, does no moving about. Jelly-fish are taken from place to place by waves and currents, worms and the *Mollusca* are very feeble movers, if they get about at all. Talking generally, animals without a backbone are, at best, slow movers. That is true, specially, of the sea animals. Of those forms without backbones which have taken to living on dry land, we have, in the *Arthropoda*, a number of animals which are very quick. They do not, however, get very great in size or become very strong. From the point of view of being quick and strong at the same time, the cephalopod is the best of the animals which have no backbone. Some of these animals are as much as fifty feet long, and they are able, when forced, to go at a very great rate. They do this by sending water out violently through the end of a pipe placed under their mouths. The force of the water sends them back a little way, and then another burst of water sends them back a little farther. This is a system in which a great amount of force is used in relation to the effect produced. The system

of moving which has come to development in the fish is a very much better one.

The fish is one of the *Vertebrata*, and the earliest *Vertebrata* of which we have any record were fish-like forms. These early *Vertebrata* were not sea-animals. We come across them in strata put down by water which was not salt, and it seems probable that their development was the outcome of the more complex needs of animals living in running water, such as rivers, in comparison with those of animals living in water which is not moving. The view is taken that the increased power of controlled motion was responsible for the development of the backboned structure, which is a very good one for this purpose. It is probable that this increased power was made necessary by the violent changes which took place on the face of the earth at the end of the Proterozoic era. The waters of the earth, which till now had been without motion, were then changed, by the slope of the land, into moving waters, so that only those animals which were able to keep themselves from being moved were able to go on living in the water.

The second great event in the history of evolution, as we see from our records in stone, was the coming of the *Vertebrata* to dry

land. To do this the development of two new things was necessary for the fish. It had to have a different sort of breathing apparatus, and it had to have the power of moving on dry land. There are still in existence fishes which have two ways of breathing. In addition to the breathing-apparatus normal in fishes they have the apparatus needed for breathing on dry land, and in dry weather, when the water in which they are gets low and thick, they come up to the top and take in air. Three or four sorts of these fishes are in existence now, and the general view is that land *Vertebrata* have come from the same animal as these. Fishes which got a new sort of breathing-apparatus in this way did not all come to the stage of living on dry land. In those fishes which did not go on, the new apparatus became an air-bag supporting them in the water, and so made their adjustment to the conditions of a water existence better.

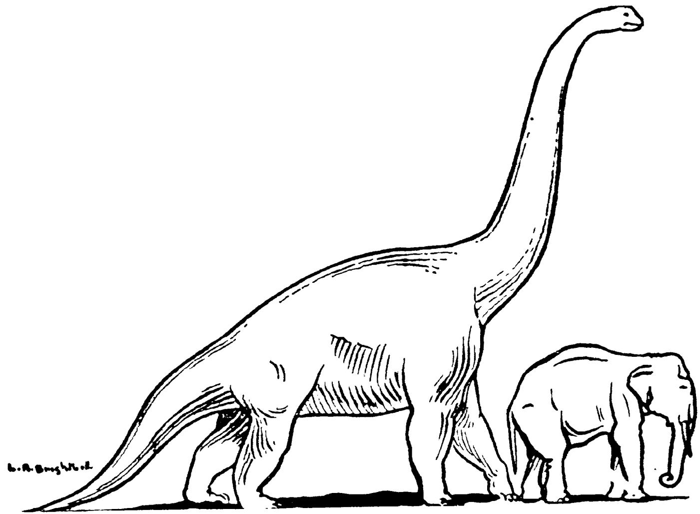
How they made the second change, and became able to get about on dry land, is still very uncertain. There are some fish in existence, however, which are able to get about on dry land with the help of their swimming-parts, so that, though we have still not come across anything which makes it clear how the early fish did this,

the fact that they did so is not very surprising.

But even when they had got as far as this, there was something further to be overcome by the fishes which took to dry land. All the early fish had other animals for their food, and though the land, at the time they came out of the water, was well covered with plants, there were almost no animals for them to take as food. There was nothing but a small number of scorpions and insects. For this reason, most of these early amphibians went on living and getting their food in the water. Even now, only a very small number of such animals have got completely free from a water existence. Almost all of them have to be in the water when they are young. But, hard though it was for them, there were some of these early animals which were able to make the necessary adjustments to take up the new existence, and from them come all the land *Vertebrata* of the present day.

The first of the *Vertebrata* to become completely land animals were the reptiles. The true reptile, which came from the amphibians, had got to its full development by the end of the Paleozoic era. This development probably had something to do with

the fact that the earth was becoming increasingly dry at that time, so that some of the water was drying up, making the old amphibian way of living harder. But the great time for the evolution of the reptiles was in the later era, the Mesozoic era. For 100,000,000 years the reptiles were the most important form of living thing. They took up their existence in the water, on the land, and in the air ; the food of some of them was grass, of others meat. Among the land reptiles were the greatest land animals there have ever been. The weight of a number of them was over thirty tons, and of some more than forty. They were the strongest group of animals there had so far been, and, as we have said, their rule was a long one—it went on for 100,000,000 years. And then they suddenly went off the face of the earth, nobody is able to say why. There is a theory that the change in the weather conditions of the Mesozoic era, when the earth got increasingly cold and dry, may have been, in some degree, responsible. Further, it has been noted, though we are not fully able to give the reason for it, that animals which go on getting stronger and greater in size come to a 'dead end.' Possibly the very small brain reptiles have in comparison with their



A dinosaur from British East Africa, the greatest which has ever been come across, in comparison with an Indian elephant (*Elephas ludicus*).

Brachiosaurus—from bones in Field Museum, Chicago, and Natural History Museum, Berlin.

bodies has something to do with this. A man whose weight is twelve stones has a brain with a weight of 3.3 pounds. At this rate an animal whose weight was a ton would have half a hundredweight of brain. The brontosaurus, one of the great Mesozoic reptiles, had a weight of thirty-seven tons and a brain whose weight was two pounds. This is less than an ounce to a ton, in comparison with the man's half-hundredweight to a ton.

We have said that the reptiles, in addition to living in the sea and on land, took to the air. They never truly had the power of flight, however ; they never had wings. Their flight was a sort of long jump—they came slowly down through the air. The apparatus for doing this was a fold of skin down the sides of body and legs. In some reptiles this became a wide bit of skin uniting the legs with the neck and tail. With this skin stretched out the animal would give a jump into the air, guiding itself with its tail. True birds, warm-blooded and feathered, came into existence in the Mesozoic era, and there is no doubt that they were a development from reptiles. The earliest bird we have record of, *Archeopteryx*, which we come across in the Mesozoic era, has head-bones, mouth-bones, front legs, and so on,

which are like those of the reptile in a number of ways. Later examples of Mesozoic animals have become much more bird-like.

In the Mesozoic era another of the great forward steps in the history of evolution was taken. Mammals came into existence. Mammals being, like birds, warm-blooded animals, are more able to make an adjustment to different weather conditions and are able to do more than any other animals. But in the Mesozoic era the reptiles were in a stronger position than any other animals, and the only mammals of which we have any record were small and in an incomplete stage of development. It was not till the era which came after, the Cenozoic era, after the destruction of the great reptiles had taken place, that the mammals went on to their full development. Mammals may be placed in three stages of development—'monotremes,' 'marsupials,' and 'placental' mammals. The monotremes have eggs, as the reptiles do, though the young, when out of the egg, get milk from the mother. The marsupials have got a stage further than this. Their young come from them living, but very incomplete, so that they have to take them about in a sort of bag, where while

they are babies they take in food from the mother. The kangaroo (*Macropus*) is an example of this stage of development. The placental mammals, the group in which all the highest animals are, have young which come from them in a very high stage of development. In addition, the higher mammals have better brains than the two earlier sorts. There were no placental mammals in the Mesozoic era. The forms which have been come across bedded in the Mesozoic strata are all marsupials or monotremes. And judging by these records, they were small in size and number.

It was in the later era, the Cenozoic era, that the evolution of mammals took place on a great scale. All the chief sorts of mammals—the horse, tiger (*Felix tigris*), cow, sheep, elephant (*Elephas*), whale, etc.—came into existence in this era. And certain other sorts of mammals came into existence which, for one reason or another, were to go completely off the face of the earth. We may give as an example the baluchitherium, a great animal of about twenty tons in weight, and able to take the leaves off trees more than twenty-five feet high.

The great stage to which we now come in the history of living things is the develop-

ment of man. Man's nearest relations are the 'anthropoid apes,' as they are named—the orang (*Simia satyrus*), chimpanzee (*Troglodytes niger*), gorilla (*Troglodytes gorilla*), and gibbon (*Hylobates*); and the common view is that these, together with man, all come from the same sort of animal. The history of how this came about is still not clear. It seems probable that man came from some animal like the lemurs (*Lemuridæ*), which was the common starting-point for monkeys and apes (*Simiidæ*, *Cercopithecidæ*, and *Cebidæ*). But we have no signs of what the steps in between were. Discoveries have been made, however, of the bones of early men, who were much more ape-like than ourselves, and the earliest of these go back for about 500,000,000 years.

The discoveries of the bones of early men do not make a complete chain taking us from some ape-like animal on to man as he is today. There seems to have been more than one line of development from the early animal which was the starting-point of it all. Some of these lines went branching off into the different species of monkeys and apes. Others went branching off into different species of men. Our species is the end point of one of these lines of development. Other

species of men which were produced by evolution went completely out of existence. From the discoveries which have been made, it is impossible to put together the history of the development of our species. It may be that we do not come from any one of them. Or it may be that present-day man comes from some species which was the outcome of two or more of these species. There are very different opinions on this point.

The discovery of what are possibly parts of one of the earliest men was made by a medical man in the Dutch army named Dubois near Trinil, in Java, in the year 1891. He came across the bones forming the top of the head and one back tooth. Later an upper leg bone and second back tooth were unearthed. In a very short time there was a sharp division of opinion about these discoveries. Some said that they were nothing but parts of a great gibbon. Others said that there was no reason for the belief that the bits were all parts of the same animal. But, later, the same sort of discoveries were made near Pekin, and it is now the general view that the Javanese bones and teeth are those of some early form of man. From small bits of the body, experts in the structure of bones are able to get a number of facts. They are able

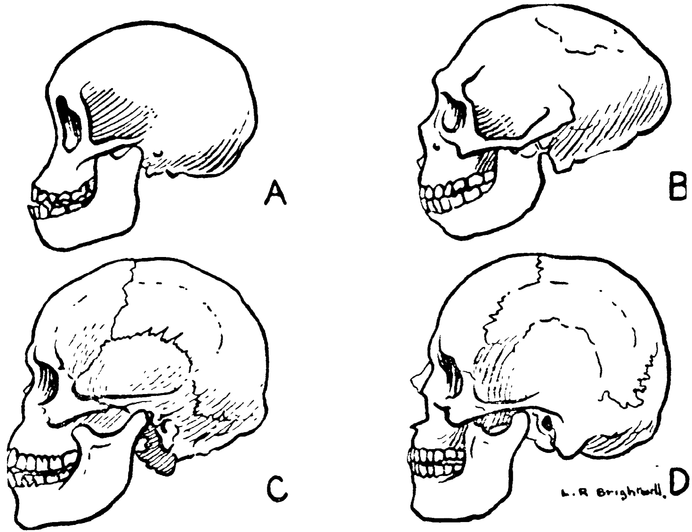
to say that *Pithecanthropus*, as the Javanese man is named, had a brain very much smaller than that of present-day man. The position in which he kept his body, however, was not at all ape-like. It is probable that he was almost as upright as we are ourselves. Judging from the strata in which the parts of Pithecanthropus was bedded, he seems to have been living 400,000 to 500,000 years back.

Another discovery was made, at Mauer in South Germany in 1907, of a lower mouth-bone. This bone is part of some very early animal. It is of great weight and size, and might, from that point of view, very well be the mouth-bone of an ape. The teeth, however, in themselves and in the way they are fixed into the bone, are completely like those of a man. And in other ways the bone is like the mouth-bone of a man. The animal of which this bone was a part was named by the man who made its discovery *Homo Heidelbergensis*, as a sign that it is a species of man. Unhappily no other bones have come to light. This is the only sign of this species of man which we have come across. It is probably about 400,000 years old.

A discovery which is in some ways even stranger is that of the bones of Piltdown

man, *Eoanthropus*. The discovery was made at Piltdown, on the Ouse, Sussex, by Mr. Charles Dawson, a man of law living in that part, who was interested in the early history of man. He came across the incomplete bones of the head and a lower mouth-bone. Here again, a number of authorities at first took the view that the two things were not parts of the same animal. It was said that, while the head-bones might be those of a very early man, the mouth-bone was part of a chimpanzee. Some years later, however, a second discovery of the same sort was made some two miles away, and this made it quite clear that the two bones were parts of the same animal. There is now agreement that Eoanthropus was an animal which had some of the qualities of a man and some of the qualities of a chimpanzee. These bones are certainly very old, and it is possible that they are the earliest men's bones which have so far been unearthed.

Bits of other species of early man have been come across in different places, but we are very uncertain about how old most of them are. We are in a much better position when we come to give an account of the bones of Neanderthal man. The discovery of a number of examples of this species has



Sorts of men.

A. Java Ape Man. B. Neanderthal.
C. Tasmanian. D. European.

been made in different European countries and in Palestine. Neanderthal man was a short, strong, not very well-controlled animal, unable to keep himself in a fully upright position. The size of his brain was even greater than that of present-day man, but it was lower in development. He made a great business of putting his dead under the earth, was able to make use of fire, and was expert at making stone instruments. He was living at the same time as the reindeer (*Rangifer tarandus*), the woolly rhinoceros (*Rhinoceros antiquitatis*), the mammoth (*Elephas primigenius*), and so on, the animals living in Europe when the earth was last covered by ice. It is probable that the species went completely out of existence about 20,000 years back, though some authorities take the view that certain species of men living now have in part come from Neanderthal man.

The bones of men who came after Neanderthal man may well be looked on as the bones of late species very like those in existence to-day. The most noted of this later species, which were on the earth before the birth of history, is the Cro-Magnon man, so named because of the place where the discovery of his bones was made. It has been said that this species is in almost all ways the

best-made man physically who has come to our knowledge. The bones of a number of this species have been unearthed. The males were normally well over six feet tall ; the women, however, were little taller than those of the present day. Their head-bones are quite like ours. These men, in addition to being expert workers in stone, had a great feeling for art, as we see from the stonework, pictures on metal, and paintings which we have come across in and on the walls of the stone hollows which were their living-places. This species is no longer in existence. North and south of the Himalayas there are men and women with faces very much like the Cro-Magnon face, and the Sikhs are like them in form and size. The bones of other late species have been unearthed, but it is not at all certain how old they are.

§ 3

THE PROCESS OF CHANGE

We have given an outline—a very short outline—of the history of living things on this planet. We see that we are forced by the time order in which the different animals came into existence to the decision that there has been a process of evolution. We are now faced with the question : How did this process of evolution come about ? By what was it caused ?

We have seen that it is through the genes that qualities are handed on to offspring, and that genes are able to undergo mutations. The qualities of an animal are fixed by the special genes which it has in its cells. If the genes are changed, the qualities of the animal are changed. Such changes, as we have said, are taking place all the time. Most of the mutations have the effect of making only very small changes in the animal in question—changes so small that they do not come under

observation. In other examples the changes may be great enough to be noted by a trained eye. And it has been seen that sometimes one mutation, a change in one gene, may be enough to have very marked effects. For example, the colour of an animal's hair may be changed from black to brown, or from black to yellow, by one mutation. Another mutation may make a change in the colour of the eyes. The loss of horns in cows, and the loss of the tail in cats, are caused by a change in one gene.

Mutations are taking place all the time, so naturally, in time, animals will come into existence which are in some ways different from the animals which have gone before them. Some of the ways in which they are different may have no effect at all on their existence, but some of them may be of such a sort as to have a very clear connection with their chances of living. They may make those chances greater or less, because outside conditions are forcing themselves on an animal all the time, rewarding certain qualities, and having no use for others. Those animals whose changes from the normal make them better able to make the best of the conditions they are in will clearly have a better chance of living a long time

and producing offspring. The change which has taken place in them is handed on to these offspring. These offspring will in time undergo further changes, which may, in their turn, be a help to them or get in their way.

We see that two things have to be taken into account. There are the chance changes in the animal, and there is the effect of living conditions in sorting out these changes. It has to be kept in mind that this process of selection is not all in the same direction. For example, an animal which has the power of living in a certain range of heat may undergo a mutation as an effect of which it will do better in a different range of heat. If, now, there is a change of the same sort in the weather conditions, the mutation is clearly a help to him. But if the weather conditions make a change in the opposite direction, then he is clearly worse off. In the same way a great reptile plated with some hard material was certainly helped by this covering when he was living on land which was half under water, because the water took off much of his weight. But when the land became dry he no doubt made the discovery that he was almost unable to get about at all. For millions of years mutations in the direction of more and more plating had been in his

interests. Then came a change in his living conditions, and what had been in his interests became against him.

Is it possible that the complete history of living things on this planet is based on chance mutations and the reaction of outside conditions on them? Possibly most biologists are happy about such an account, though there are a number who are against it. In support of the theory it is necessary to keep in mind the very long time for which the process has been going on. We are talking of something which has taken hundreds of millions of years. It does not seem impossible that all the chance changes there have been over such a very long time might in themselves be enough to be the cause of the wide range of different living things. Further, we have to keep in mind that not all the changes are small. And we have no knowledge of the rate at which mutations took place in the past.

There are some biologists, however, who are of the opinion that there are signs here and there that mutations did not come about completely by chance. There are examples, they say, of animals in which the mutations were in the same direction all the time. These mutations take place as the effect of

some inner dr ving-power, and they go on even when they are no longer of use to the animal. This theory, the theory of Orthogenesis, has been given much attention by biologists, but it is far from having general support.

We gave space earlier to a discussion of Lamarckism, the theory of evolution current before Darwin, which put forward the view that mutations were caused by the attempts at adjustment made by the animals in question, and we have said that this theory has not a great number of supporters. There is no doubt, naturally, that changes may be produced in an animal in this way, but it seems very clear that it is not possible for such changes to be handed down. They have no effect on the genes of the animal, and so may not be handed on to offspring.

There are three sorts of changes, which may be named 'fluctuations,' 'Mendelian combinations,' and 'mutations.' Fluctuations are those changes in the animal after its development which come about through the use or going out of use of different parts, or through changes in food, weather conditions, etc. Such changes do not have any effect on the genes, and are not handed on to offspring. Mendelian combinations take place

simply because, as we have seen, the offspring gets half its chromosomes from its father and half from its mother. There are generally a number of ways in which this combination may be made, and every new combination naturally gives a new group of qualities to the offspring. In this way changes may be produced without changing the genes in any way, but simply by grouping them differently. Such changes, naturally, may be handed down, and they have done something in the direction of giving the material for evolution. But the truly important steps in evolution come about through mutations. We are not able to say what the causes are of the mutations which take place in the natural process of things. It seems that these causes may come in part from the structure of the genes themselves and in part from outside conditions. Though mutations seem to take place by chance, it is not true that every possible mutation takes place. As was pointed out by T. H. Huxley, whales never have feathers or birds whalebone. But so far we are not able to give any reason for the mutations or the limits on the mutations.

The record of geology makes it clear that higher living forms came into existence later

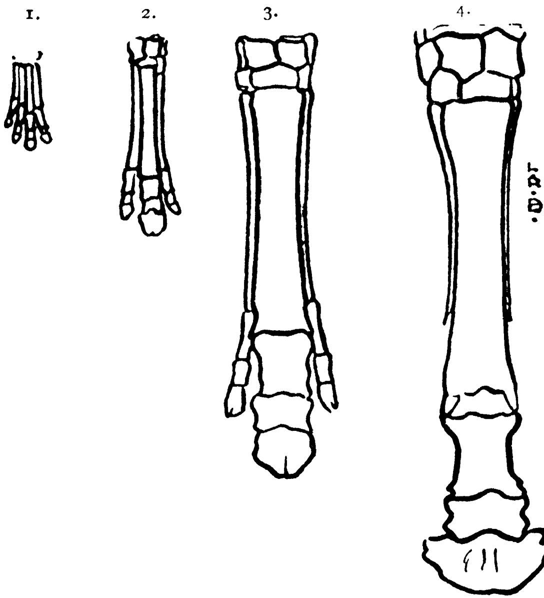
than the lower forms. But it would clearly be false to give a picture of the process of evolution as one in which lower forms gave place all the time to higher forms. There are animals at all stages of development in existence side by side at the present day. The earth still has room for the amœba in addition to man. The common lamp-shell (*Lingula*) has gone on unchanged from the start of the Paleozoic era, that is, for 500,000,000 years. In such examples it seems that the animal has got to a point where its adjustment to its living conditions is so complete that there is no profit in further change. As long as there is no important change in the living conditions, the animal goes on unchanged. There are even examples where it has been in an animal's interests to go back from a higher to a lower stage. Take, for example, sacculina, an animal which has a dependent existence, living on different sorts of crabs. It is without senses, legs, or digestion system. It is little more than a bag of gametes. It gets itself fixed on to the crab, sends out branched roots in all directions into its body, and through them takes food out of it. But this animal was at one time one of the free-swimming *Crustacea*, with legs like those of a

crab, an outside framework, and so on, as we see from the form which it has at the start of its existence, after coming out of the egg. It has made the discovery of a simpler way of living, but only at the price of going back to a lower form. Other examples of the same sort might be given. Adjustment to its conditions does not necessarily take an animal forward in the scale of evolution.

A very good example of forward evolution is given by the history of the horse. Early horses are seen to have been in existence at the start of the Cenozoic era, and we are able to keep in touch with their development after that down to the present day. The earliest horses we have come across are small animals about a foot high, and with four toes on the front feet. In process of time we see one of these toes increasing in size, and the others getting smaller. While this is going on the animal itself is increasing in size, and its teeth are becoming better. After a time the animal is a three-toed animal, the other toe having almost gone from view. The two outer toes of the three now get smaller, so that the animal, though having three toes, puts its weight in running on only one. The two toes get smaller, little by little, till in our times they have

become simply vestiges. Other developments have gone with these, all with the tendency of making the horse stronger, quicker, and better able to take care of itself. The history of this development has been worked out from tens of thousands of examples which have been unearthed. An almost equally detailed history may be given for some other animals.

It is interesting to see that the evolution of the horse has been, in fact, a process of adjustment in one special direction. The horse has become an animal designed more and more for one way of living—an existence on great smooth stretches of land with grass for its food. Here its surprisingly strong and good teeth and its quick legs are a great help to it in getting its food and keeping out of the way of danger. But the very fact that its adjustment is so complete has made all other development impossible for it. If it was, for some reason, cut off from its present way of living, it would not be able to take to any other sort of existence. It would not take to living on other animals, or become good at getting up trees, or go into the water or the air. In comparison with the early reptiles which did all these things we see that the horse is without any power of change.



The evolution of the 'horse's hand' or early foot.

1. Hyracotherium. (*Eocene.*) 2. Mesohippus. (*Oligocene.*) 3. Hipparion. (*Pliocene.*) 4. Present-day horse. (*Recent.*)

The great animals living on meat, the great natural danger to the horse, whose development took place at the same time, are equally limited in their powers of adjustment.

In looking at some special line of evolution we frequently see that the discovery of different examples, representative of different times, has been made in different parts of the earth. In fact, the distribution of animals and plants, present and past, frequently seems, at a first look, very surprising. But it all becomes clear when we take into account the great changes in the geography of the earth, which, as we see from geology, took place in the past. At one time there were land bridges joining bits of land between which seas now come, and at one time deep water made divisions in what is now one long stretch of land. Australia, for example, has not been cut off from the rest of the earth all through history. But it became cut off before the development of true placental mammals. That is why there were only the earlier sorts of mammals, monotremes and marsupials, in Australia. Africa was at one time cut up by seas into two separate parts. And such changes have frequently taken place more than once in the long stretch of time of which geology has record. The evolution of any

special sort of mammal is naturally dependent, in a very great degree, on special conditions. In the history of a number of animals there have been bursts of evolution, as one might say. These bursts have their start in certain places, and the wider distribution of the new sort of animal then comes about in the normal way. At the same time, it is possible that certain parts to which earlier sorts of animal came may have become cut off from the place where the new development is in process, and that there is nothing in the conditions of those parts to be the cause of an outburst of the same sort. In this way the marsupials got to Australia, were cut off from other animals, and went on being marsupials for millions of years.

§ 4

THE CIRCLE OF LIVING

THE chief way in which plants and animals are different is in the process by which they get their food. Plants are able to take their food straight from the chemicals round them. Animals are unable to do this. All animals, in the end, get their food from plants. Naturally, they frequently do not get it straight from plants. There are insects living on plants, small birds living on insects, and greater birds living on small birds. But without plants all animal existence would be impossible. The chemical substances taken in by plants are turned by them into more complex forms, and it is only in this more complex form that they are of any use to animals. After the death of an animal, processes are started by which the complex substances are broken up and these elements then go back into their first condition. In this form they are again of use to plants, and so the circle is

started again. It is true that there would be a circle even without animals. Dead plants would be broken up chemically and the chemicals they had taken up would be ready to be made use of again. But the process would be a slow one. By having animals in the circle the process becomes very much quicker. For this reason the animal–plant organization may be looked on as a sort of apparatus for turning certain chemical elements into more complex substances.

The most important of the chemical elements which takes part in this circle is carbon. In the number, range, and complex organization of the substances formed by it with other elements, carbon has no equal. It is the chief substance in the chemistry of living things. Other elements, such as oxygen, nitrogen, phosphorus (P), etc., take a very important part in living processes, but carbon, more than any other element, seems to be completely necessary. The carbon used by living things is in the complex form of carbon dioxide. There are about 2,500,000,000,000 tons of this substance in the air round the earth, and possibly twenty to twenty-five times this amount in the seas, stretches of inland water, and rivers of the earth. It has been worked out that about

$\frac{1}{1000}$th of this amount takes part in the circle of which we are talking.

Green plants, under the effect of sunlight, take CO_2 straight from the air. They give off oxygen, and make a number of complex substances with the carbon. Animals take the plants, and the carbon they get in this way goes, together with oxygen, to make carbon dioxide again, and is breathed out by the animal. In this way the circle is complete. This circle, however, is very far from being the full story of all the carbon dioxide which is playing its part in the natural process of things. In addition to the breathing of animals, the process which goes on in their bodies after death gives back a certain amount of carbon dioxide to the air. The same process in plants does not give back carbon so quickly. In fact, much of their carbon becomes locked up in the form of 'peat'—earth chiefly formed of dead plant material—and coal, which is another substance formed, to our knowledge, from dead plants. Through all the different eras a great amount of carbon has been stored up in this way, carbon taken, in the first place, from the air. In our present time, man, by burning peat and coal, is giving this carbon back to the air at a great rate. If there were

no balancing processes at work, our coal fires and the great fires in our metal works would have the effect of increasing the carbon dioxide in the air to twice the old amount in about five hundred years. Outbursts from the middle of the earth and springs have the same effect of putting great amounts of carbon dioxide into the air. Among the balancing processes, those which take carbon dioxide out of the air, we have to take into account, in addition to the forming of peat, the weathering of stone. In the process of weathering, stone takes in carbon dioxide. It is hard to say how much is used up in this way, but certainly a great amount is so used. It has been worked out that the amount in the stone beds of which geology has knowledge is 30,000 times the amount now present in the air. But what does most to keep the balance equal is the sea. This has about twenty times as much carbon dioxide as the air, and keeps a balance almost all the time, taking in carbon dioxide when there is more than the normal amount about, and putting it back when there is less than the normal amount.

The oxygen circle naturally has a connection with the carbon circle, because carbon dioxide is formed of the two elements. The

chief work of plants is to get the carbon and oxygen separate in carbon dioxide, while the chief work of animals is to put them together again. Some authorities take the view that all the oxygen of the air has been formed from carbon dioxide with the help of plants. The question is still, however, somewhat uncertain.

Another of the substances which living things are unable to do without is nitrogen. This element goes through a far more complex circle than carbon. It is an element which seems to be necessary to living things, but the question of how to get enough of it is very complex. The amount of nitrogen present in the air, however, is far greater than that of carbon. If we take the amount of air resting on a square foot of the earth, then this air has in it over 1,500 pounds of nitrogen. It has only a quarter of a pound of carbon. But the fact is that free nitrogen, as it is in the air, is of no use to the living body. It is only when it is locked up in certain complex chemicals that it may be taken in as food, and there is not a great amount of these complex chemicals. It has been worked out that the amount of nitrogen which is in this form and goes through the circle of living things is only about $\frac{2}{1,000,000}$ths of all the nitrogen in the air.

It is possible that a small number of plants are able to take nitrogen straight from the air, but this is not the normal way. The work of getting the nitrogen of the air into the liquid or solid form in which it will be of use to living things is done by a special group of bodies. These are the nitrogen-changing bacteria. These bodies are in the earth and make the nitrogen of the air into complex chemicals which the roots of plants are able to take in. Certain sorts of plants—peas, beans (*Vicia faba*), clover (*Trifolium*), alfalfa (*Medicago sativa*)—have these bacteria in the bulb-like growths on their roots, and the two things working together, the plant and the bacteria, make the nitrogen into a form in which it is of use to other living things.

Most plants get their nitrogen from the salts of ammonium (NH_4), the salts of nitrous acid (HNO_2), and of nitric acid (HNO_3) which are present in the earth. These substances are, in addition, attacked by certain bacteria, with the effect that a certain amount of free nitrogen gets back into the air. Other ways in which nitrogen gets back into the air are through fires in woods and the burning of wood and coal. All these operations let free nitrogen into the air. Nitrogen, in a complex form, is taken from

plants by animals which get food from them. Part of this nitrogen goes away from the animal as waste, and part of it is kept in the bodies of dead animals. But when the chemicals in the waste or the dead bodies are broken up a certain amount of free nitrogen gets back into the air. The waste from places where animals are put to death for the meat market is responsible for much nitrogen getting back to the air. The system by which the waste from the drains is taken away in great towns to-day is another cause of great nitrogen losses.

It is clear that these losses have to be put back if the circle of living is to go on. How are they put back? We have seen that certain plants get their nitrogen straight from the air. Outbursts from the middle of the earth are another way in which we get the necessary nitrogen. In such outbursts, as at Vesuvius and Etna, certain complex forms of nitrogen are sent up into the air, and these substances are washed down into the earth by rain. Certain nitrogen substances are sent down to the earth by the operation of electric forces in the air. It has been worked out that the amount of nitrogen substances got in these ways are a little more than the losses.

In addition to these natural processes, we have to take into account the effect on the nitrogen circle of the things men do. Man seems to have had a knowledge of the value of animal waste in making earth fertile from very early times. A great step forward was taken with the opening up of the nitre (KNO_3) beds in Chile in 1831. Without this discovery the present system of farming, which gets the most out of the earth, and the increase in the number of men made possible by it, would not have come about. It is an interesting fact, however, that only quite a small amount of the nitrogen got from Chile is used for making substances to put on the earth. Much more of it, in fact almost half the complete amount, is used for making war materials. In using the nitre beds, as in using the coal beds, we are, naturally, taking substances we will not be able to put back. It is possible that the nitre beds were formed by outbursts from the middle of the earth, though we are not certain about this. But, however they came into existence, it is certain that the process took a very long time, and that they are not being formed at anything like the rate at which they are being used up. Happily, there is now no need to be troubled about this fact, because man has

made the discovery of a way of producing complex nitrogen substances from the nitrogen in the air. There is more than one way of doing this, and the forming of nitrogen substances from the nitrogen in the air now takes place on a great scale. The war, naturally, was responsible for a great development of this young industry, because nitrogen substances are needed for war materials. In 1909 only 1 per cent. of all the nitrogen needed was produced in this way. By 1917 the output had got to 30 per cent., and by 1920 to 43 per cent.

The amount of nitrogen in a complex form produced in this way is small in comparison with the amount washed down by rain all over the earth. But the nitrogen substances washed down by the rain go all over the place, on bad earth and fertile earth equally. The great value of making nitrogen substances is that they are in man's control, and may be used wherever they are most needed.

Carbon dioxide and nitrogen have, as substances of the air, an equal distribution everywhere. The element which comes after these on our list, phosphorus, which is very important in the circle of living, has not the same distribution. It is a good example of the elements necessary to the living body

which are not normally moved about—the 'inherently immobile' elements.

Generally, unused earth has a certain store of phosphates. But in time, and when land is formed, this store gets less and less. Part of this loss is probably caused by rain with carbonic acid (H_2CO_3) in it, which takes up the phosphoric acid (H_3PO_4) salts in the earth, so that, in the end, they are washed out to sea. But another part of the loss is caused by the fact that the phosphorus taken up into plants and then into the bodies of animals and men does not all get back to the earth in the right way. When we put the bodies of dead men in the earth, for example, though phosphorus does get back to the earth, it does not do so in the way which makes it most fertile. But a much greater waste is caused by our present system of taking away the material from drains. Through this system a great amount of phosphorus is taken off every year to the sea. At present we get over this loss by using phosphorus which has been stored up for hundreds of thousands of years in the beds of phosphate stone, in the same way as nitrogen substances are got from the nitre beds of Chile. We have, however, no further store of phosphorus parallel to that of the

nitrogen in the air. There is only quite a small amount of phosphorus in existence, equal to about 0.14 of the face of the earth. For this reason the loss of phosphorus, a necessary element of the circle of living, is a serious, and even a troubling event.

Not all the phosphorus washed into the sea is wasted, and we have here a very interesting example of a natural circle of living. Phosphates washed into the sea make food for sea-plants, which in turn are the food of different sea animals. Part of the phosphorus so taken goes to make the bones and other hard parts of these animals, and, at death, go down to the sea floor. Outbursts from the middle of the earth, such as take place in times of which geology has record, sometimes send these phosphates up out of the sea, and so we get our phosphate stone. Another circle is caused by the birds living on fish. These birds, which go about in great numbers, have their living-places on stone-covered islands or on masses of stone near the sea, and here, in time, there comes to be a great amount of their waste, or 'guano,' which is sometimes put back in the earth by man. Unhappily these stores do very little to put back the loss of phosphorus which is going on all the time. It has been worked out, for

example, that in the United States there is a loss of twice as much phosphorus as it gets from its phosphate stone ; that is to say, its loss every year, measured in phosphate stone, is about 3,000,000 tons. For this reason it is not surprising that in the view of a number of authorities, the loss of phosphorus which is going on all the time in the land, with its necessary effect on the nation's food, is very serious.

Of the other elements which take part in the circle of living, there is no need to say very much about potassium (K), sulphur (S), and iron. Potassium salts are put down by natural processes. These stores of salts were controlled in Germany, and in the war the development took place of processes for getting potash (KOH) from the waste of certain stone works and other materials. But when the German stores again came into the market these processes were given up. There are natural complex substances which have sulphur in them. Plants take them in, and so, in their turn, do animals. They come out with animal waste, and in this way go back again into the earth. Iron is present only in very small amounts in living bodies, but it is very important to them. It is the iron in the chlorophyll of plants which makes them able

to get their carbon dioxide from the air. Most of the iron in the body is in the red blood cells, and here its work is to take oxygen through the body, so that the oxygen which is breathed in is able to get to the different parts of the body.

In addition to the transport of materials in the circle of living, there is, naturally, a current of power. This power comes from the sun. The amount of power from the sun which is stopped by the earth is less than $\frac{1}{2,000,000,000}$th of all the power which the sun is giving off. A very small part of the rest of the sun's power goes on to other planets, but far the greater part of it simply goes off into space. Of the amount of power which comes on to the earth, only 65 per cent. of it is taken up by it. The other 35 per cent. is given back into space, chiefly by the clouds. The amount of heat which gets to the earth from the sun would be enough to make liquid a covering of ice 424 feet thick every year. Of this amount of power only 0.12 per cent. is taken in by green plants, and so this is the amount of power on which the circle of living is dependent. Put in this form, this amount of power seems very small, but it is equal to twenty-two times the power given by all the coal produced in a year. The

greater part of this power, 67 per cent., is taken by trees. The plants which are farmed for the needs of man take 24 per cent.

We see that all the power used by the circle of living is a very small part of all the power the earth gets. A much greater part, about 250 times as much, is used in producing winds. In addition, sea currents take a great amount of power. But the most important user-up of power is the process by which water is taken up by the heat of the sun, given back to the earth in the form of drops, and taken by rivers back to the sea. It has been worked out, for example, that the power used by the sun in driving off water from a square kilometre of sea in the warmest parts of the earth is over 1,000,000 horsepower.

§ 5

THE NATURAL BALANCE OF THINGS

WE have seen that the elements which take part in the circle of living go through plants to animals and back to plants again, and that bacteria have an important part in the process of building up and in the process of getting broken down. Animals would be unable to go on living without green plants, and green plants would be unable to go on living, in their present numbers, without animals. In any living society the way in which different structures are dependent on one another is very complex. Though the starting-point of a food-chain is normally among green plants, there are a great number of different food-chains, on land and in the sea.

A strange thing about the organization of any society of living things is that it keeps so very much the same. Such a society will go

on living in the same place for a very great number of years so long as it has not been troubled by man. It is very hard for any new sort of animal or plant to get into such a place. Take, for example, Mount Ritigala, a sharply sloping mountain of less than 3,000 feet in the middle of more or less flat land in the north of Ceylon. The island generally has wet, very warm weather, but in the north part, where Ritigala is, it is very dry. But the top of Ritigala, which is covered by clouds, is quite wet. The flowers on Ritigala, however, are almost the same as those in the dry part of the island. Only a small number of the species common in the wet part of the island have made any headway on the mountain, though the weather conditions are almost the same. The society which has taken up its existence there is so fixed that anything from outside, even if the weather conditions are right for it, is only able to make headway there very slowly.

When the land is clear, however, when no living society has taken up its existence, the distribution of plants and animals goes on at a surprising rate. A good example of this was given by the noted outburst, in 1883, on the island of Krakatoa, between Sumatra and Java. This was so violent that it was re-

sponsible foı the destruction of half the island. Every living thing on it and two nearby islands was put an end to. Even on islands fifteen miles away the destruction was very great. Ten miles farther away were the islands of Java and Sumatra. If there were to be living things on the island again they would have to come from seeds transported a great distance on winds or currents. But in three years about seventeen species of plants had got back on to the island, and a number of mosses and different sorts of fern (*Filices*). Ten years later there were no less than fifty species of flowering plants, tall grasses, wooded plants, and a small number of trees. In 1906, twenty-three years after the event, there were a great number of plants and trees, among them being the fig (*Ficus*) and the coconut (*Cocos*). And there were mosquitoes (*Culicidæ*), ants, wasps (*Vespidæ*), birds, and lizards. In this way a far greater number of new living things had taken up their existence in twenty-three years on the dead land of Krakatoa than had been able, in hundreds of thousands of years, to get on to Ritigala where other plants had made a place for themselves first.

What sort of things do well in any part is dependent on how ·vet it is, on the light, heat,

and other conditions. If outside forces are not at work, there come into existence on the land those sorts of things which do best in its special conditions. The society of living things is then said to have got to its 'climax,' or highest point, and, as we have seen, it is surprisingly fixed. When we go farther north and south we make the discovery that there are different sorts of climax dependent on the different weather conditions. In the middle band of the earth the normal climax are the rain woods, green all through the year, and with a great number of tall trees. When we go north and south from this part, it is not wet enough for the support of trees so near together, and they become more spaced out. Where there are wastes of sand, it is so dry that the trees get smaller and more widely spaced, and even the smaller plants are no longer able to give a covering to the earth, but are seen in broken, separate masses. When we get farther away from the middle of the earth we come to wetter places, and here we see the great stretches of grassland. Very far north and south, where the conditions are bad, we come across the lower sorts of plants—mosses and lichens (*Lichenes*) —forming quite a thick covering for the earth, till, when we get near the great ice-

fields, there are only a small number of small plants here and there.

If we make a journey from low lands to very high lands we go through almost the same changes as in going north or south.

Surprisingly different groups of living things may be seen in the same way in very narrow limits, as, for example, in and round a small stretch of water. From the middle to the edges we have divisions, as one might say, in which are different sorts of things changing in relation to the different degrees of water, light, and so on, of which they are in need. The natural tendency of all animals is to go on increasing their numbers without limit, but the conditions of heat, etc., keep every species to certain places. In addition to unlimited increase being stopped in this way, the number is, naturally, further kept down by competition. Some prickly pears (*Opuntia vulgaris*) were planted for interest in East Australia. In a small number of years there had been such an increase in the numbers of these plants that thousands of square miles were covered by them. At one time they were increasing at the rate of an acre a minute. It seemed as if all East Australia would be covered by prickly pears. In the year 1907 the mouse (*Mus musculus*) underwent

a great increase in number in Nevada. Birds and mammals were causing their destruction at the rate of 1,000,000 a month, but they went on increasing. Such developments are generally ended by disease. There is a general outburst of disease which takes off most of the animals, so that their number is very much less than normal. Even without disease, the fact that food is limited would keep any animal from increasing in number for ever. Frequently, however, when food gets low the animals go to some other place. The great locust (*Pachytylus migratorius*) flights of history are an example of this. An almost equally noted example is that of the lemmings (*Myodes lemmus*), little rat-like animals from Scandinavia. At certain times great numbers of them go from the places where the young are produced, and, overcoming everything which is in their way—getting over walls and swimming rivers—get to the sea. They make an attempt to get across even this, and the outcome is the destruction of all of them. It is recorded that a ship has gone steaming for a quarter of an hour through a mass of these swimming lemmings.

These times of over-development take place very regularly. Almost all species go through times of increase and times when

there is a falling off of numbers. Their numbers go up to a highest point, down to a lowest point, and up to a highest point again. And for any given species the highest points come at regular times. The snow-shoe rabbit (*Lepus americanus*), for example, gets to the point of greatest increase every eleven years. So do the lynx (*Felis lynx*) and the red fox (*Vulpes vulgaris*). The arctic fox (*Vulpes lagopus*) gets to this point every three years. And the great journeys of the lemmings take place about once in three years. We have no idea why these increases are so regular.

We see that, in parts which are untouched by man, things are in a very delicate condition of balance. We have forces working for the destruction of that balance, such as those responsible for some species over-producing itself, but, after a certain point, an opposite force comes into operation and the old condition of balance comes back again. As we have seen, in every part of the earth which is clearly marked off by a special group of conditions, there is a natural tendency to get to the climax which is right for those conditions, and this climax is something which is not readily changed.

The balance is chiefly broken by man. We have said something about the planting of

the prickly pear in Australia. A number of examples of the same sort might be given. Man's development of plants and animals is sometimes a cause of trouble. As an outcome of it, new questions frequently have to be faced. The growth of the prickly pear, for example, which was a very great danger, has only been stopped after men of science have given much time to the question. Steps were taken, in different countries, to see which were the greatest dangers to the prickly pear, and in the end the discovery was made of four insects living on the prickly pear, and on the prickly pear only. These insects were transported to Australia, where their numbers are now great enough for them to be able to keep the prickly pear from getting any farther. This is only one example. A common way of keeping down the numbers of anything which has become over-produced is to see what things are naturally a danger to it, and much work of great value has been undertaken on these lines. We have not long been conscious of how delicate and complex the natural balance is. Almost everything man does has a tendency to the destruction of this balance, frequently in quite unlooked-for ways. The discovery was made, for example, that over great stretches of land, cows,

pigs, sheep, and horses were being attacked by strange diseases which had bad effects on their growth, causing them to be unfertile and of less value for meat, milk, wool, and skin. In the end the discovery was made that these diseases came through the animals not having enough of certain salts in their food—such salts as those of iron, calcium (Ca), phosphorus, etc. Man was putting more animals on to these lands than were able to be supported naturally by the earth. Further, by shipping off the dead bodies and skins of the animals he keeps the chemicals which the animals have taken into their systems from getting back to the earth. Under natural conditions an animal's death takes place where it gets its food, and the chemicals in it have a chance of getting back to the earth there. This circle is broken by man. One outcome of looking into this question has been that new and better sorts of grass have been produced. In our power of producing these grasses, as in our power of producing better sorts of grain, we see signs of the control which a more complete knowledge of biology will give us. The cows, pigs, etc., produced by man for his use, are another good example of the way in which, by using the laws of biology for his purposes, man is

able to make the natural condition of things better.

Other examples of the way in which one thing is dependent on another, unpleasing, but very important for man, are given by the natural history of a number of diseases. Malaria is an interesting example. There are two or three sorts of this disease, and all of them come from bacteria which get into the blood of man through the bite of a mosquito. The bacteria go through different stages of development in the body of the mosquito (*Anopheles*), and at last get into the mouth of that insect. A mosquito bite puts these bacteria into the blood of man, where they get into the red blood-cells and are started on a further stage of development. For some time they go on increasing inside the blood-cells, then come bursting out of them, and get into other blood-cells. Then there comes a quiet stage, in which the bacteria do nothing inside the blood-cells, and at last their death takes place. It is possible, however, that in this resting-stage a mosquito may give the man a bite and take in some of his blood. If the red cells so taken up have the malaria bacterium, the process of development is started in the body of this new mosquito, and so another mosquito becomes

able to give the disease. Malaria may not be given by man to man, or by mosquito to mosquito. It has to go from mosquito to man and from man to mosquito.

An even more complex chain of connection is given by the history of the liver fluke (*Fascida hepatica*), an animal living in and getting its food from the liver of sheep and other animals living on grass. The eggs of these animals are taken, by a liquid made by the liver, into the lower digestion system of the sheep, and from there come out with the waste, and so get outside the animal's body. In warm, wet weather these eggs are broken and from them come very small bodies only $\frac{1}{200}$th of an inch long. These are very different from the fluke from which they came, which is about an inch long. This little animal goes about looking for a certain sort of snail. If it does not come across such a snail it is unable to go on living ; if it does, it gets into the body of the snail, there increasing in size and having a number of offspring. Then its death takes place. These offspring are not like the fluke which gets inside the snail or the first fluke. They are small, worm-like bodies. They get their food from the body of the living snail, and have offspring like themselves, which again

have other offspring, and so on. By the time the cold weather comes a change takes place. The fluke does not go on having offspring like itself, but a new sort of animal comes into existence with a great head and a small tail. These animals make a hole through the snail and get out and on to wet blades of grass or other leaves. If now a sheep or some other animal takes this bit of grass, these animals get into its liver, increasing in size there and producing eggs. In this way the circle is complete, and the liver fluke makes a start over again. Our natural disgust at watching such animals is almost overcome by our surprise at the strangely complex rhythm of their existence. Even if we gave a million such examples we would not have given a complete account of all the different and delicately balanced forms and processes of living.

Among living things there are an unlimited number of connections. It is impossible to get a good picture of the evolution and present existence of any species by looking at that species only. The example we have given makes this fact very clear. Equally clear examples may be given where the relation is not that of an animal to its food, or of an animal to some other animal

on which it is living, but one of an exchange of help. We said something earlier about the way in which plants of the pea family and certain sorts of bacteria gave help to one another. Here carbon is fixed by the plant and nitrogen by the bacteria, so that one is helped by the other. A great number of examples of such help-relations might be given, sometimes between plant and plant, sometimes between animal and animal, and sometimes between plant and animal.

We see that, under natural conditions, any part of the earth will get to a point at which a balance is kept between the different sorts of living things which are supported there. It is true that from time to time there is an over-increase in some direction, but through disease or some other cause, the old balance quickly comes back. The greatest danger to the natural balance of things on our planet is man. Animal and plant existence is surprisingly fixed in its ways. But, as the theory of evolution makes clear, it is all the time, though very slowly, undergoing change. On the time-scale of history this change goes almost unnoted. But on the time-scale of geology change is seen to be the keynote of all living things. A tendency to change, our present-day theories say, is bedded in the living

substance itself. Mutations are frequently taking place, caused we have no idea how. The degree to which any one of these mutations is important enough to give us a new sort of animal is dependent on the outside conditions. No doubt for every mutation which is of value there are others which are not. Every step has to be judged by its effects. Sometimes it seems that no change has been necessary. There is a sea-animal—the lamp-shell—which has gone on unchanged from the earliest times. It was living and doing well in those far-off early seas in the same way as it is living and doing well for itself now. Its adjustment to the conditions in which it is living seems to be so complete that no development has taken place in it for hundreds of millions of years. But not all change seems to have been to give the animal in question a better adjustment. We have said before that sometimes an animal seems to have gone on changing without any good reason in a certain direction, though the change has been of no value to it, and may even have been against its interests, and that an example seems to have been given by the great reptiles. As we have seen, these animals were the most important things on the earth for 100,000,000 years. And then,

quite suddenly, they went out of existence. They had taken the decision, as one might say, to get on by becoming strong and of great size. Their size became such that no competition with them was possible. And having got to this stage they went on increasing in size till their great bodies kept them from moving freely. They were no longer able to go about quickly enough to get the food necessary for their support. Another example of what seems to be the same sort of unreasoning impulse, though not so serious in its outcome, seems to be given by a group of fish of the same family as the dog-fish (*Scyllium*). These fish, probably because it was of use to them, have been getting flatter bodies and thinner tails. But the development seems to have gone further than the point at which it is of any use to them, and is simply making them strange-looking. The tail has become nothing but a sort of whip end. Other examples of this sort of automatic development might be given. The suggestion has been made that such developments are, sometimes at least, the effects of other changes. Though of no value in themselves they are a necessary outcome of the chief line of evolution which the animal is working on in its interests. These tendencies have

the effect of troubling the natural balance. But it is more or less true to say that the slow change which is going on all the time in living things is a development from one balanced condition to another.

THE END

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